RAPID PROTOTYPING USING ROBOT WELDING - PROCESS DESCRIPTION

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ABSTRACT

Rapid Prototyping is a relatively recent technique to produce component prototypes for industry in a much shorter period of time, since the *time to market* a product is essential to its success. A new Rapid Prototyping process which uses metal as the raw material had been under development at Cranfield University in the last few years. The process uses a Gas Metal Arc fusion welding robot which deposits successive layers of metal in such way that it forms a 3D solid component. Firstly, a CAD system is used to draw the solid model, then some information relative to the types of layers and dimensions is incorporated in the model and the solid model is then automatically sliced. Reports on the welding time and conditions for the component's production are automatically generated as well as the robot program.

The concept of this Rapid Prototyping process is deeply explained in this paper. Every step of the process is described by a full chart. The Hardware and Software used in this system are also described. Since a computer model is used a calibration of the system is required and therefore the most important aspects of Robot and Cell Calibration are also discussed.

KEYWORDS

Rapid Prototyping, Metal, CAD, Robotics, Welding, Computer Simulation

1. INTRODUCTION

This process was first described by Ribeiro in [1] and with some more detail some time later by Ribeiro [2]. The time to market a product is essential in nowadays so competitive industry and therefore to reduce prototyping time, it has often been stated that a need to automate the production of 'one off' components for development and evaluation is necessary. Casting technique is a time consuming process and expensive especially if used to make one component only. Most of the rapid prototyping processes evolved in response to this requirement and these use resin based materials which are not always suitable for testing purposis. Metal based prototypes are often required and additional processing is necessary to convert resin based materials to a useful form. In this process the component is formed by melting and depositing the metal using the GMA welding process. A CAD drawing system is used to create the initial solid shape and a welding robot is used to manipulate the welding torch.

The first step is to draw the component in a CAD system and then a slicing 'add-on' of the CAD program is implemented to generate the desired layers which will form the robot program. The slicing system was described by Ribeiro [3]. Additional data is required to indicate bead geometry and the material used. Since a CAD model is used a robot and workcell calibration is necessary to indicate exactly where the component is going to be built in relation to the robot. The welding conditions like voltage, current, wire feed speed and robot speed are automatically generated by the program in order to achieve the required bead geometry and stable operating parameters. Welding studies had to be carried out previously to derive the best conditions and these were carried out by Norrish [4] and the parametric equations were generated by Ogunbiyi and Norrish [5]. The robot program to build the component is automatically generated and can be computer simulated with the use of a robot simulation program to check for collisions or other problems such as access to difficult areas of the component. Should the robot program need to be changed it can be done manualy and after that it is then compiled and downloaded to the robot.

2. GENERAL DESCRIPTION

Two different CAD/CAM manufacturing processes can be used to make a component: the subtractive and the additive. In the first one, material is removed from a massive block of material. In the second one, material is added to create the desired shape. The shape of the component to be built and the material to be used influences the choice for one of these processes.

Rapid Prototyping processes are additive processes because they consist of depositing layers of material, for example, by solidifying a photopolymer or thermoplastic material or by adding sheets of paper and joining them with an adhesive. Most traditional Rapid Prototyping processes work in a similar way which consists of a movable device depositing or solidifying material on a table or container. This new Rapid Prototyping process is comparable to the traditional ones as far as basic principle is concerned and it is hereby described: a robot is used in conjunction with a turn table, the deposition device is a welding torch and the raw material will be the fused metal.

Many reasons do not allow a human to carry out this task: the precision with which the robot has to be moved, repetition of movements, the hazardous aspects of welding, boredom and tiredness. This indicates that manual welding techniques would not be feasible for this type of process. In addition the main objective of Rapid Prototyping is to automate the whole process as completely as possible. Therefore, robots are the most desirable machines to perform this operation. They do not get tired or bored, they do not hurt themselves and they are ideal for performing repetitive and accurate tasks. In the proposed system, a robot is used to deposit layers of weld metal on a turn table.

3. PROCESS CONCEPT

Figure 1 shows each step of the proposed process. Each colour represents a different task or a different software package used. Each box represents an action to be taken, information about a certain entity or even a user of the information. The arrows show the direction of information flow.

The first step is to create a 3D model using a CAD program ('Graphical Information' box). Some components cannot be made in one go depending on its complexity. In that case the designer has to draw it in independent solids although close together. Each of these solids will be built separately one after the other. It is important to distinguish component and part - One or more *Parts* make a full *Component*.

For each part information has to be 'input' into the system ('Part Features' box). Information like part's name, width, build up sequential order and torch orientation are some of the fields to be filled in, to be used to generate the appropriate welding parameters ('Welding Parameters' box). After this INPUT task follows the slicing of each part. This is automatically done ('Slicing' box) and will generate polylines, within the CAD model which represent the welding trajectory for building up the desired part.

There is a text file containing the editable instructions for controlling the table and welding gun ('Welding/Table Instructions' box) and this is used as input to generate all the appropriate outputs given by the 'Automatic Generator' box. There are four automatically generated outputs. The first one is a DXF file format ('Slices as DXF' box) which contains the welding trajectory (this file can be imported to any robot simulator to check for collisions and accessibility). The second output is the robot program in ARLA language (although it could be any other robot language) as text file format for each part ('Robot Program' box). The other two outputs consist of two reports: one is for the welding technician and contains welding instructions for each part (welding parameters, timings, etc.) represented by the

‘Individual Report’ box. The other is for the production manager and contains information about the full component describing the information for each part (building time, amount of material needed, etc.) and is represented by the ‘Global Report’ box.

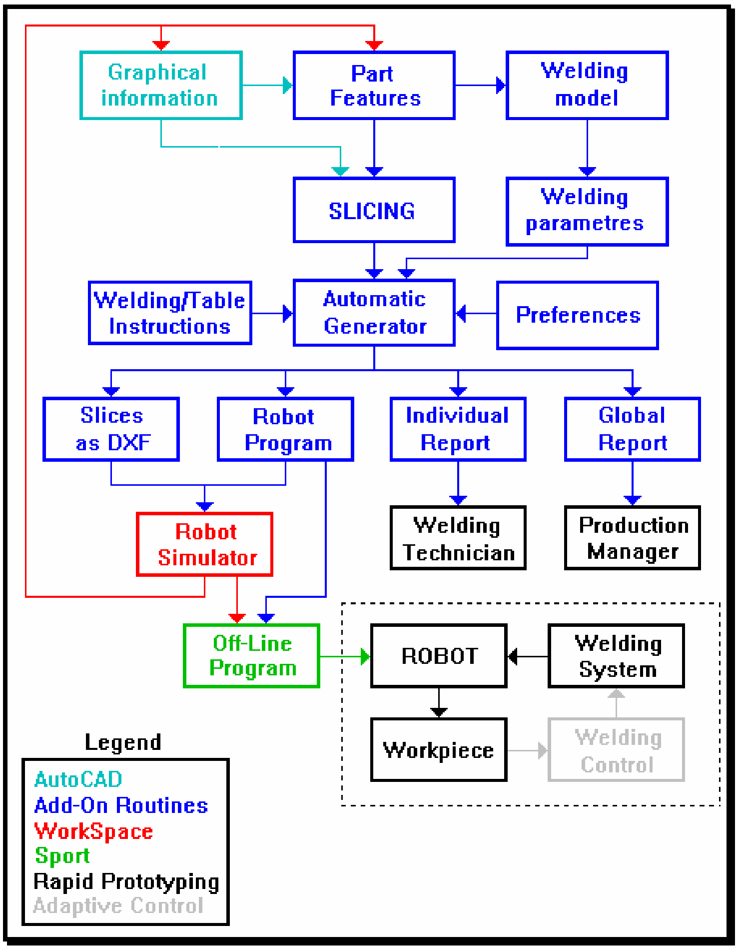

Figure 1 : 'Rapid Prototyping using Fusion Welding' Concept

All these tasks described so far were carried out within the software created by the author except the first one (drawing the model) for which AutoCAD itself was used. Should the user decide to use a robot simulator to check the robot program (‘Robot Simulator’ box), he has to read both ‘Slices as DXF’ box and the ‘Robot Program’ box.

After creating the robot program, this is downloaded to the robot via RS-232-C (with a serial link cable). A robot manufacturer software is necessary to perform this task because the binary file format is unique to each robot manufacturer. This task is represented by the ‘Off-Line Program’ box. The robot program should now have been transferred to the robot (represented by the ‘Robot’ box) and is ready to run. The welding apparatus (welding power source, welding torch and consumables) is represented by the ‘Welding System’ box. If the desired component has more than one part, the same number of robot programs have to be run, one after the other. All the robot programs can be downloaded beforehand.

The ‘Welding Control’ box is not part of this work but is seen as a very important improvement to this system. The idea is to read the component’s shape by some means of vision or any other sensor in such a way that could give some feedback to the welding system (to correct welding parameters) and if possible to the robot as well (to correct its movement or speed).

4. HARDWARE

This workcell contains a welding robot connected to a computer via a serial cable RS-232-C, and the computer is also connected to a printer. The power source and welding consumables are connected to the welding torch which is mounted on the robot arm. The robot builds the component on a table. Safety measures should be seriously taken into account (like fencing, UV filters, protecting switches, etc). This table should ideally be controlled by the robot (dotted arrow). Figure 2 represents a graphical description of the hardware used (the dotted arrows represent ideal situations and not the real work cell).

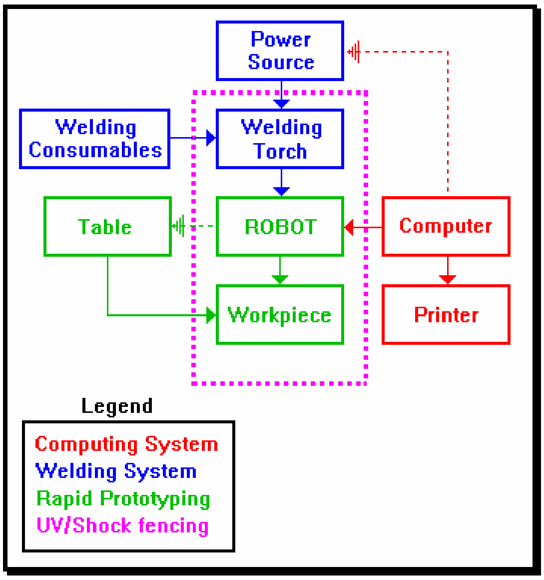

Figure 2 : Rapid Prototyping work cell Hardware

The individual system components used, were:

An ASEA IRb 2000 robot from ABB with 6 degrees of freedom with an S3 controller. It has only 64 Kbytes of memory and this represents a major limitation in the amount of programs which can be stored in it. For this process this is a major limitation because very large programs can be generated depending on the complexity of the components drawn. A turn table could be used either a stand alone or a robot linked one but for most of the samples made no turn table was used.

The welding Power Source was a Migatronic BDH 320 although some tests were later on carried out with a Migatronic BDH 550. The Welding Torch was a BINZEL PUSHPULL torch.

The only computer used to run all the software (CAD, off-line programming and robot downloading software) was an Intel 80486 microprocessor PC based with a 66 MHz clock and 16 Mbytes of RAM memory. The hard-disk capacity was 250 Mbytes. This computer proved to be enough.

The work cell had a fence around it with ultra violet filtered (UV) glasses to protect the operators' eyes. The robot and table alone had another fence with another UV filter. This second fence was also supposed to protect for physical unexpected robot movements. Should this fence opened, a circuit would go off stopping the robot and welding apparatus immediately. The consumables were all the necessary ones to a Gas Metal Arc Welding process like the wire, gas and contact tips.

5. SOFTWARE

The software used consisted of the AutoCAD ™ package, the 'add-on' developed in this work, a robot simulation software and the compiler/download software for the used robot. Figure 3 shows a graphical description of the software used.

The main reason for using AutoCAD was for its world wide use, easy interface, being an open system and accept many file formats. It is also in continuous development (although it is now in release 13 this work was carried out using release 12). Three Dimensions solids are used as well as surfaces although these were only combined in one kernel in release 13. AutoCAD has AutoLisp as its own programming language which makes it possible to customise programs according to specific application needs and this was the language used to develop the slicing routines.

WorkSpace 3.0 was used as robot simulation software. This was used for collision checking and timings control although it is not essential to this process.

Two different packages were used to compile and download the robot programs: OLP 3.0 (Off-Line Programming) is a DOS (Disk Operating System) program supplied by ABB and SPORT 1.0 (Windows based program developed by LUND University in Sweden) which performs more or less the same functions as OLP 3.0. These two programs have a slightly different dialect for the ARLA robot programs generated. This needed some considerations like generating two different versions of robot programs according to the off-line program used.

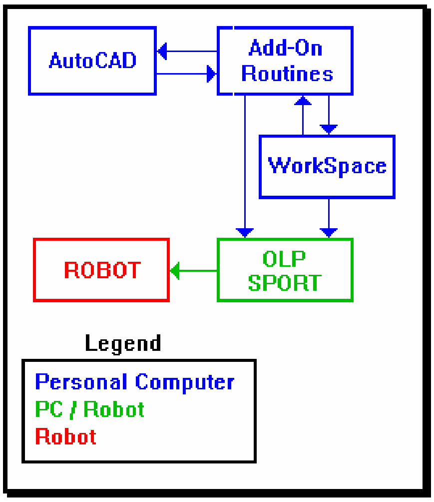

Figure 3 : Rapid Prototyping work cell Software

6. ROBOT AND WORK CELL CALIBRATION

Some work cell calibration had to be carried out to ensure correct location for build up and repeatable results and the methods employed are described in this section.

After have drawn the component in the CAD package, it is important to indicate the robot where to build it within the work cell. Therefore, the table centre co-ordinates (where the component will be built) have to be accurately located using the robot. The robot is moved to the centre of the table and the wire coming out of the torch (considering the stand-off) must touch the base plate where the component is to be started. The co-ordinates measured by the robot are read from the controller and input into the set up menu option of the software. The zero co-ordinates of the CAD model will correspond to these table centre co-ordinates. If the turn table also tilts, it must be tilted 90 degrees and the centre co-ordinates must be taken again. This is required to identify the centre position of the table when tilted.

The flatness of the table was also checked. Once this is set up, it should not need to be checked again until the table is moved although in production a periodic check should be carried out just to make sure that the table has not moved. The table surface must also be parallel to the XY plane of the robot.

If the table cannot be moved and its surface is not parallel to the robot co-ordinate system, the solid model in the CAD program can be rotated or tilted to match the location and orientation of the table. Thus, when the robot program is generated it takes into account the position and orientation of the table.

The length of the Welding Torch has to be accurately measured after mounting it onto the robot. These displacement values are represented as a (X, Y, Z) vector and set up the correct TCP in the robot memory. Once this has been set, it does not need to be reset until the torch is changed or moved, although a periodic check should be carried out just to make sure that the torch has not moved.

Each part can have a different welding orientation which can vary according to the gas flow requirements and angle of the filler wire which may influence the deposition itself. Therefore, the welding torch angle was first decided by placing the torch in the desired orientation and reading it from the robot controller. This orientation was then input into the slicing routines. A full component can have several different welding orientations but a part can only have one unique orientation. Most of the times, the orientation is kept constant for all the parts of a component.

To calibrate the robot itself an example of robot calibration to be used is Tracker system described by McMaster and Ribeiro [6].

7. CONCLUSIONS

This process was deeply tested and used, and several components were built. Some examples were described by Ribeiro in [7] and [8]. All these components were made completely automatic, from the 3D drawing up to the final component.

The main advantages of the slicing program used was that the slices were automatically created, the ARLA robot program was generated completely automatically and it was not essential to use a robot simulation package to test it, although simulation can be used to save on line time.

Should a different robot be used, this means that a different robot language has to be used. With only a few lines of code changed the system will work fine because the ‘moving’ instructions and the welding start/stop instructions are parametrised in an editable text file. In half an hour the system is ready to work with a different robot.

If the table is changed, this has to be calibrated for the first time, only to tell describe to the robot where is the table within the work cell. The system is not dependent on the welding consumables and therefore any wire/contact tip/gas. The torch can be any one although its size needs to be known and input into the slicing routines.

For all these reasons, this process proved to be a very flexible rapid prototyping system and has been very successful for all the components made so far.

8. ACKNOWLEDGEMENTS

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